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Fitzgerald et al.

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(54) **BASE STATION AND METHOD FOR DETECTING EMPLACEMENT OF IMPROVISED EXPLOSIVE DEVICES**

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(22) Filed: **Apr. 9, 2007**

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(51) **Int. Cl.**

H04M 11/04	(2006.01)
G06F 19/00	(2011.01)
G01P 3/00	(2006.01)
G01P 13/00	(2006.01)

(52) **U.S. Cl.** **702/150**; 702/188; 702/189; 455/404.2

(58) **Field of Classification Search** 702/14, 702/16–18, 56, 70–71, 75, 79–80, 187, 188, 702/189; 455/404.1–404.2, 414.1, 414.3, 455/556.2, 567, 418; 340/539.28, 539.1, 340/901, 905, 539, 531

See application file for complete search history.

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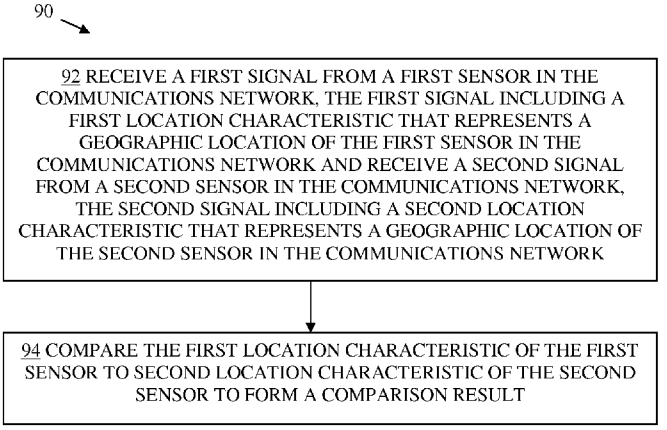
Primary Examiner — Janet Suglo

(74) *Attorney, Agent, or Firm* — BainwoodHuang

(57) **ABSTRACT**

An explosive device detection system includes sensors and base station that detect and report on suspected improvised explosive device (IED) emplacement activity within the area. When disposed within a geographic area, each sensor forms part of a wireless communications network which allows communication among neighboring sensors. As a sensor detects activity in its proximity, such as activity that indicates emplacement of an IED, the sensor transmits a reporting signal through the network to the base station. The base station is operable to detect if the signals received from the sensors are indicative of IED emplacement activity or some other activity that is not typically associated with IED emplacement activity. In the event that the base station detects activity that is indicative of IED emplacement activity, the base station can direct mobile response units to take immediate responsive action to prevent detonation of the IEDs or apprehend the perpetrators in the act.

24 Claims, 10 Drawing Sheets



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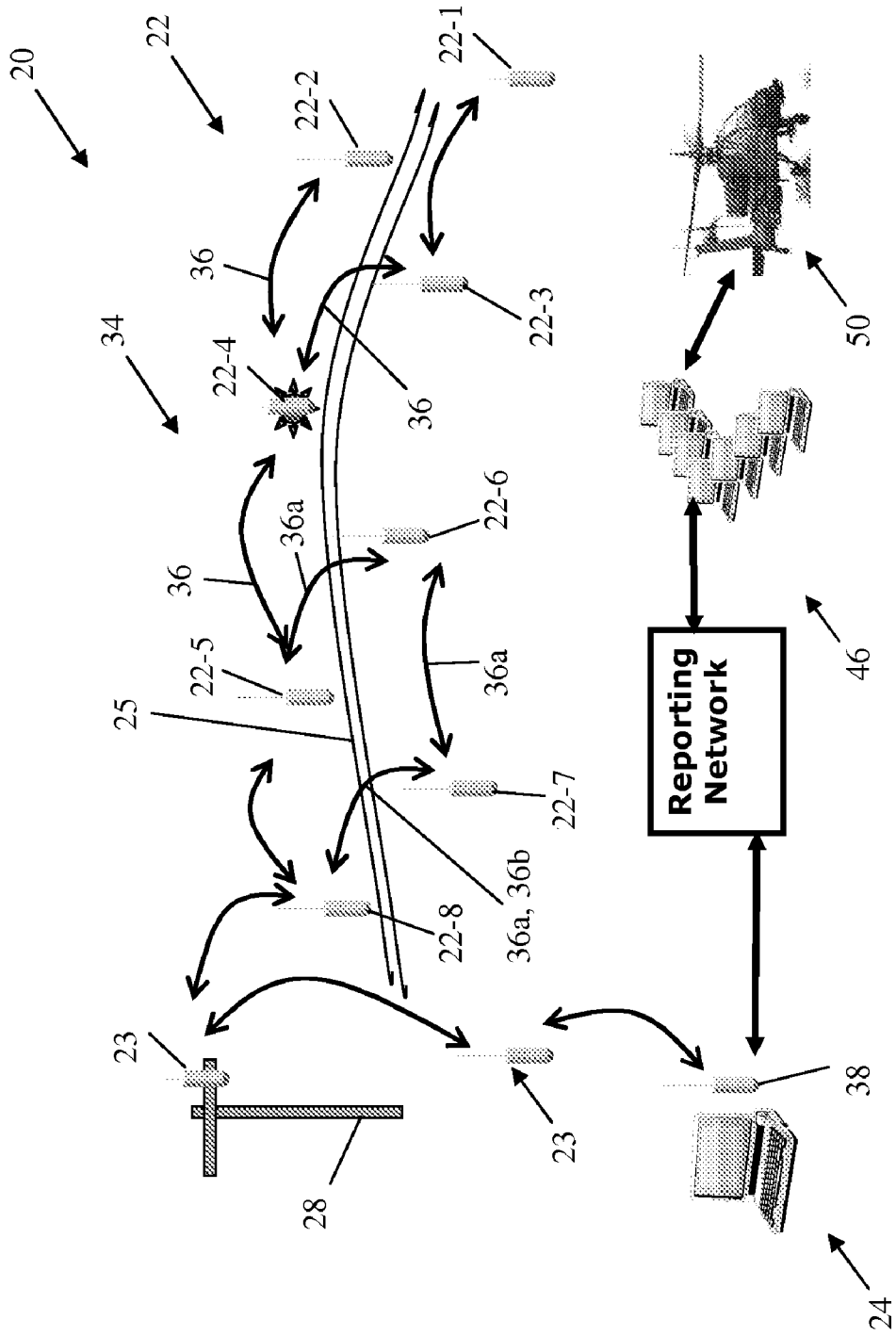
20
22
22-1
22-2
22-3
22-4
22-5
22-6
22-7
22-8
34
36
36a
36a, 36b
25
23
28
24
38
46
50
Reporting Network

FIG. 1

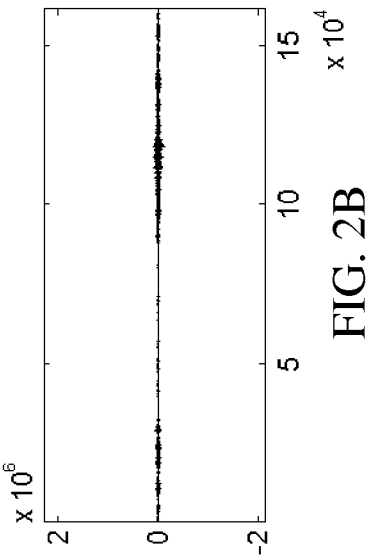

FIG. 2B

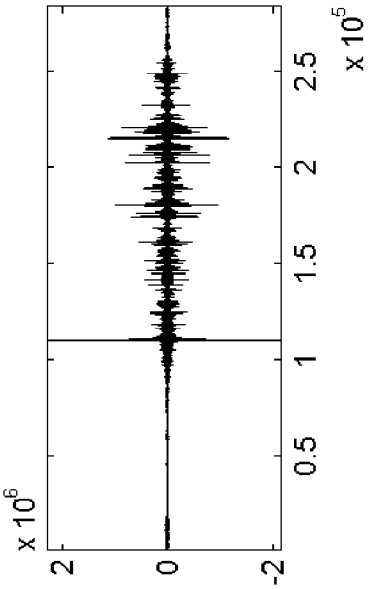

FIG. 2C

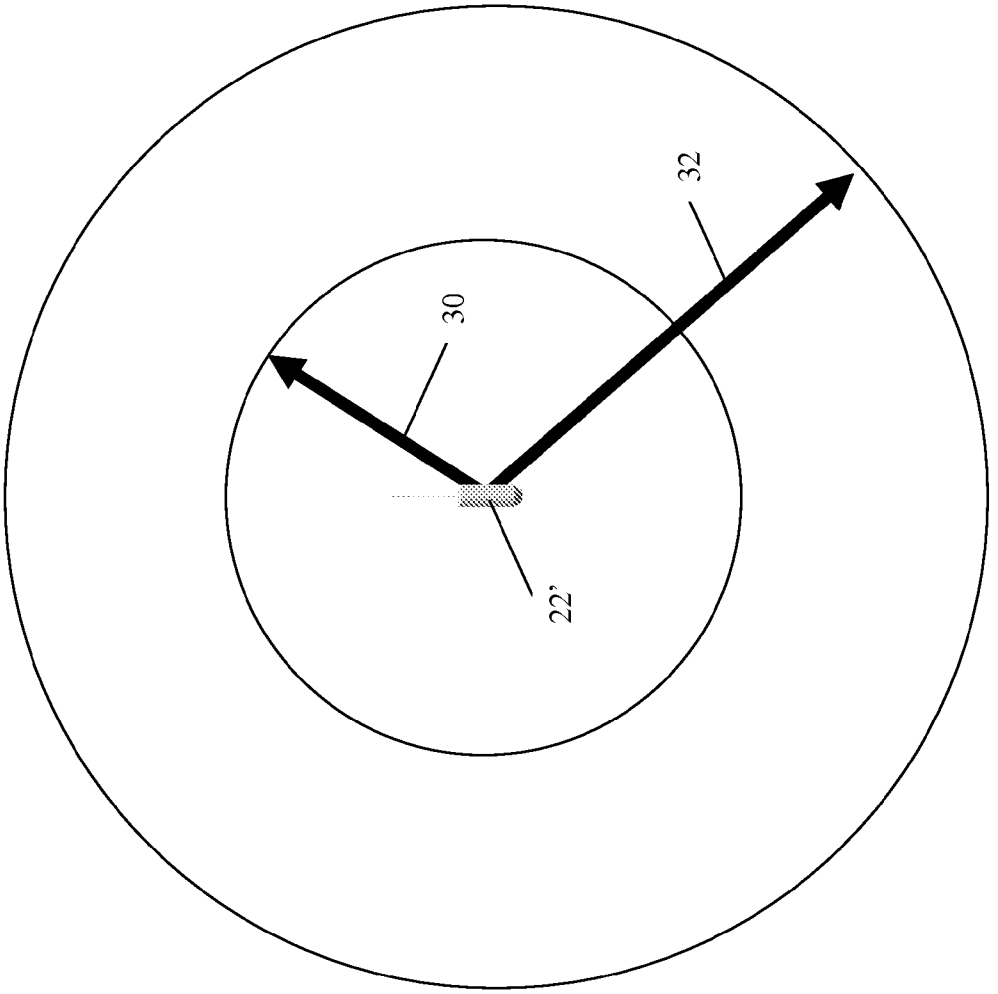

FIG. 2A

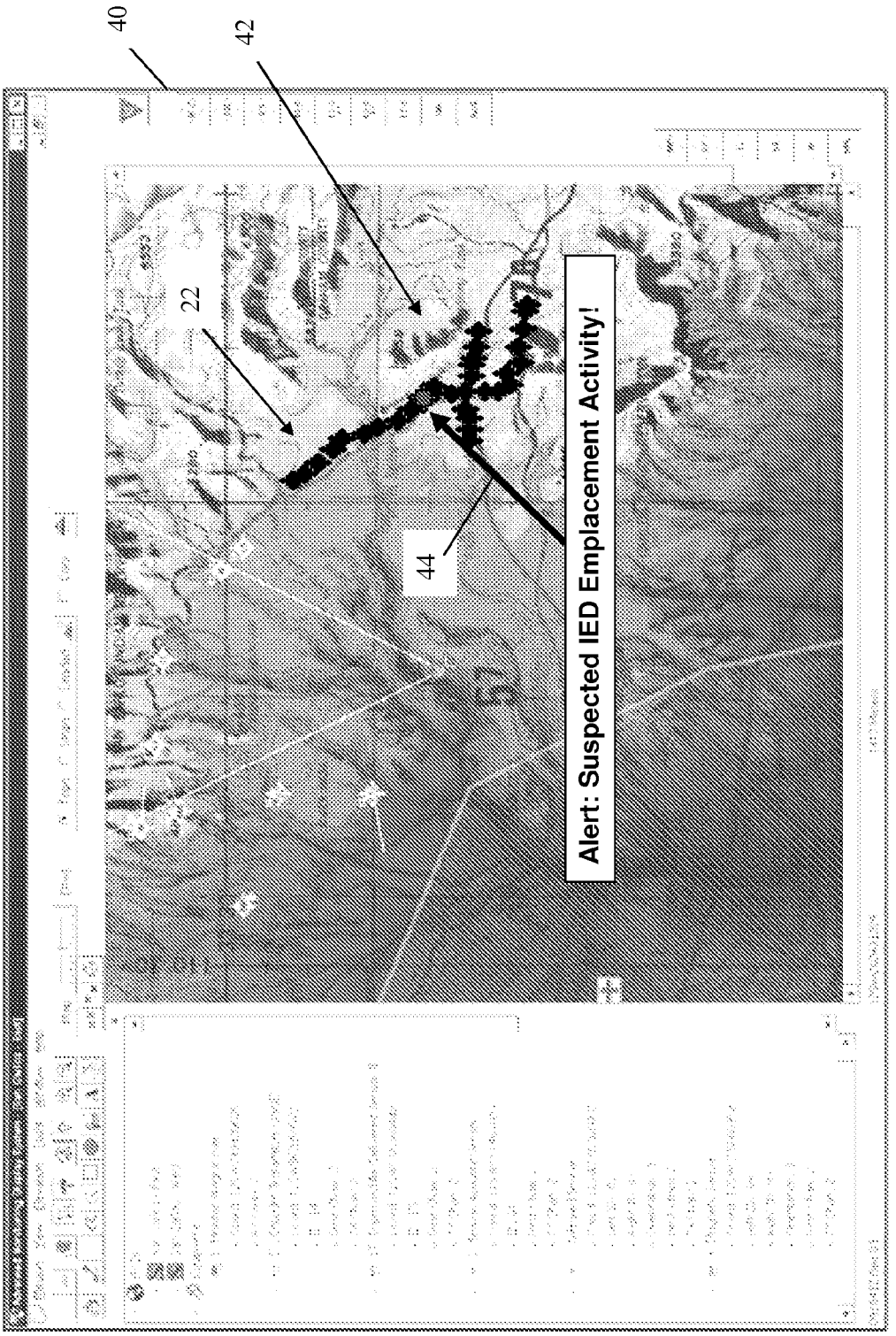

FIG. 3

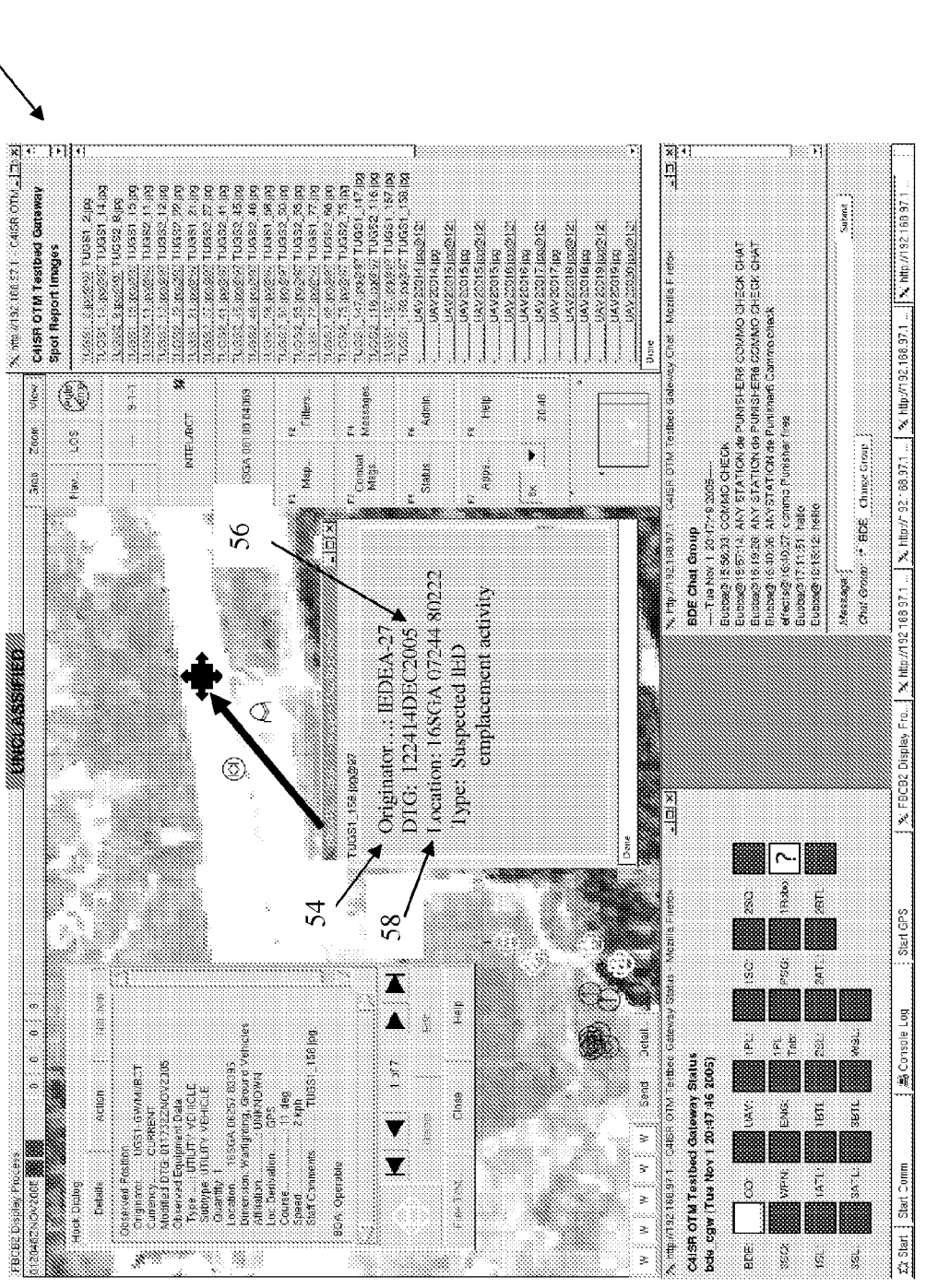
52
UNCLASSIFIED
C4ISR OTM Testbed Gateway
Spot Report Images
54
56
58
Originator...: IEDEA-27
DTG: 122141DEC2005
Location: 16SGA 07244 80222
Type: Suspected IED
emplacement activity
BDE Chat Group
C4ISR OTM Testbed Gateway Status
bde_cgw (Tue Nov 1 20:47:46 2005)

FIG. 4

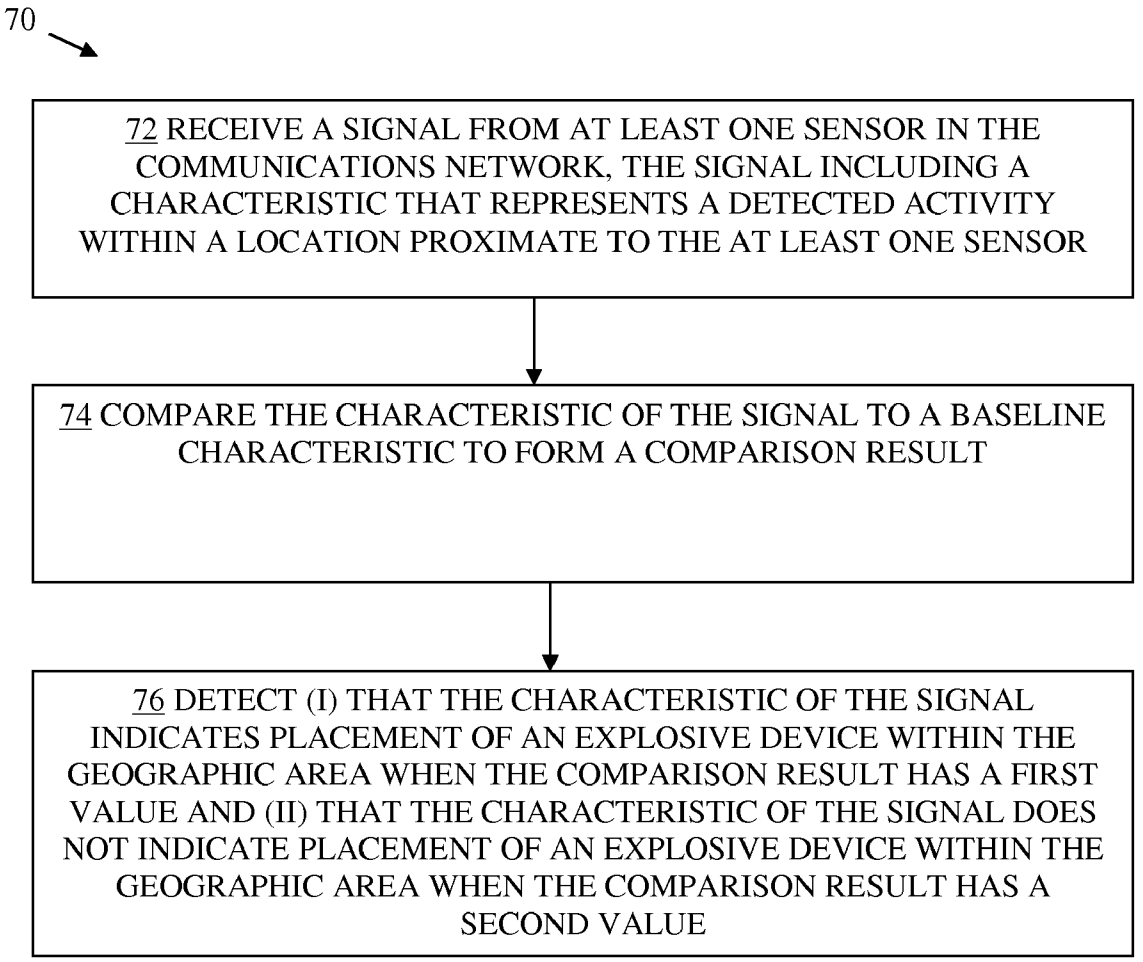
70
72 RECEIVE A SIGNAL FROM AT LEAST ONE SENSOR IN THE COMMUNICATIONS NETWORK, THE SIGNAL INCLUDING A CHARACTERISTIC THAT REPRESENTS A DETECTED ACTIVITY WITHIN A LOCATION PROXIMATE TO THE AT LEAST ONE SENSOR
74 COMPARE THE CHARACTERISTIC OF THE SIGNAL TO A BASELINE CHARACTERISTIC TO FORM A COMPARISON RESULT
76 DETECT (I) THAT THE CHARACTERISTIC OF THE SIGNAL INDICATES PLACEMENT OF AN EXPLOSIVE DEVICE WITHIN THE GEOGRAPHIC AREA WHEN THE COMPARISON RESULT HAS A FIRST VALUE AND (II) THAT THE CHARACTERISTIC OF THE SIGNAL DOES NOT INDICATE PLACEMENT OF AN EXPLOSIVE DEVICE WITHIN THE GEOGRAPHIC AREA WHEN THE COMPARISON RESULT HAS A SECOND VALUE

FIG. 5

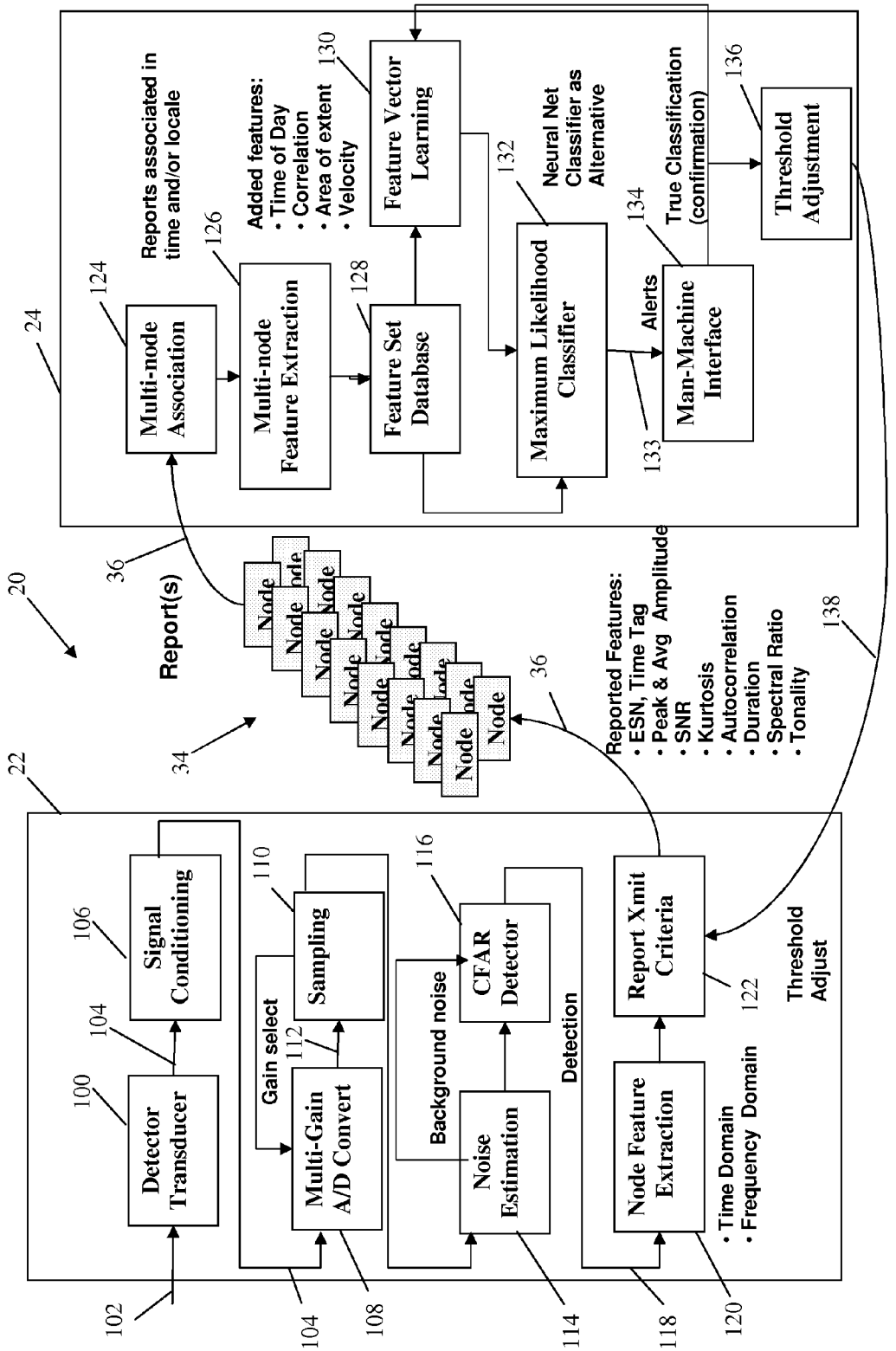
20
22
24
36
Report(s)
34
Node
Reports associated in time and/or locale
124
Multi-node Association
126
Multi-node Feature Extraction
Added features:
• Time of Day
• Correlation
• Area of extent
• Velocity
128
Feature Set Database
130
Feature Vector Learning
132
Neural Net Classifier as Alternative
Maximum Likelihood Classifier
134
Alerts
133
True Classification (confirmation)
Man-Machine Interface
136
Threshold Adjustment
138
Reported Features:
• ESN, Time Tag
• Peak & Avg Amplitude
• SNR
• Kurtosis
• Autocorrelation
• Duration
• Spectral Ratio
• Tonality
100
Detector Transducer
102
104
Signal Conditioning
106
Gain select
Multi-Gain A/D Convert
108
110
Sampling
112
Background noise
Noise Estimation
114
116
CFAR Detector
Detection
Node Feature Extraction
118
• Time Domain
• Frequency Domain
120
Report Xmit Criteria
122
Threshold Adjust

FIG. 6

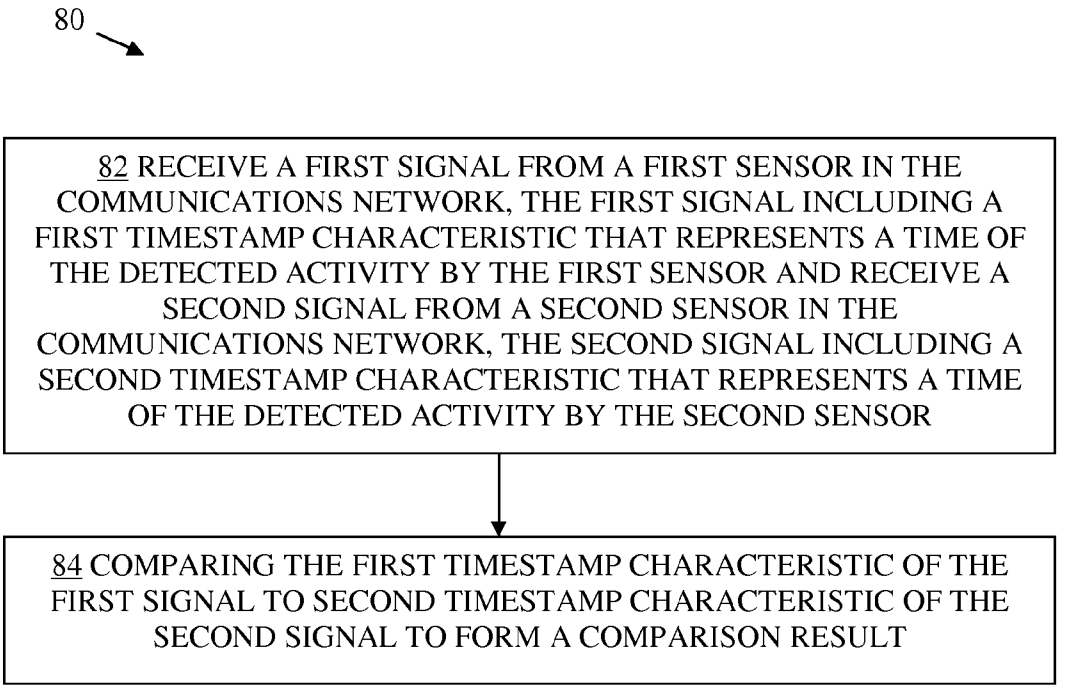
80
82 RECEIVE A FIRST SIGNAL FROM A FIRST SENSOR IN THE COMMUNICATIONS NETWORK, THE FIRST SIGNAL INCLUDING A FIRST TIMESTAMP CHARACTERISTIC THAT REPRESENTS A TIME OF THE DETECTED ACTIVITY BY THE FIRST SENSOR AND RECEIVE A SECOND SIGNAL FROM A SECOND SENSOR IN THE COMMUNICATIONS NETWORK, THE SECOND SIGNAL INCLUDING A SECOND TIMESTAMP CHARACTERISTIC THAT REPRESENTS A TIME OF THE DETECTED ACTIVITY BY THE SECOND SENSOR
84 COMPARING THE FIRST TIMESTAMP CHARACTERISTIC OF THE FIRST SIGNAL TO SECOND TIMESTAMP CHARACTERISTIC OF THE SECOND SIGNAL TO FORM A COMPARISON RESULT

FIG. 7

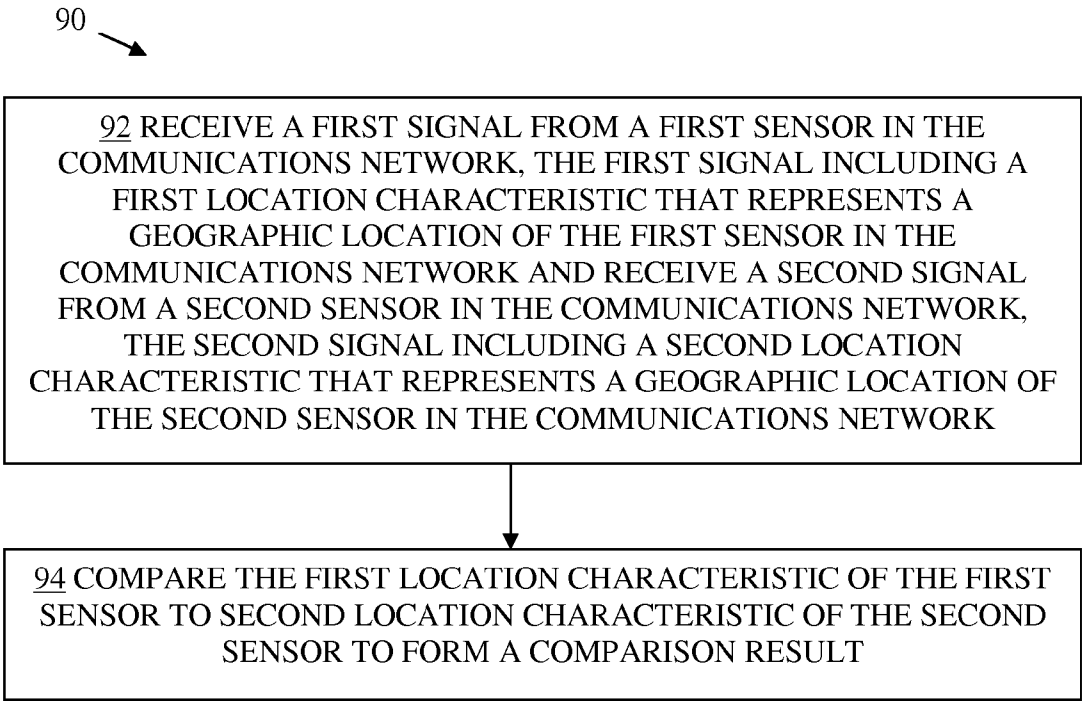
90
92 RECEIVE A FIRST SIGNAL FROM A FIRST SENSOR IN THE COMMUNICATIONS NETWORK, THE FIRST SIGNAL INCLUDING A FIRST LOCATION CHARACTERISTIC THAT REPRESENTS A GEOGRAPHIC LOCATION OF THE FIRST SENSOR IN THE COMMUNICATIONS NETWORK AND RECEIVE A SECOND SIGNAL FROM A SECOND SENSOR IN THE COMMUNICATIONS NETWORK, THE SECOND SIGNAL INCLUDING A SECOND LOCATION CHARACTERISTIC THAT REPRESENTS A GEOGRAPHIC LOCATION OF THE SECOND SENSOR IN THE COMMUNICATIONS NETWORK
94 COMPARE THE FIRST LOCATION CHARACTERISTIC OF THE FIRST SENSOR TO SECOND LOCATION CHARACTERISTIC OF THE SECOND SENSOR TO FORM A COMPARISON RESULT

FIG. 8

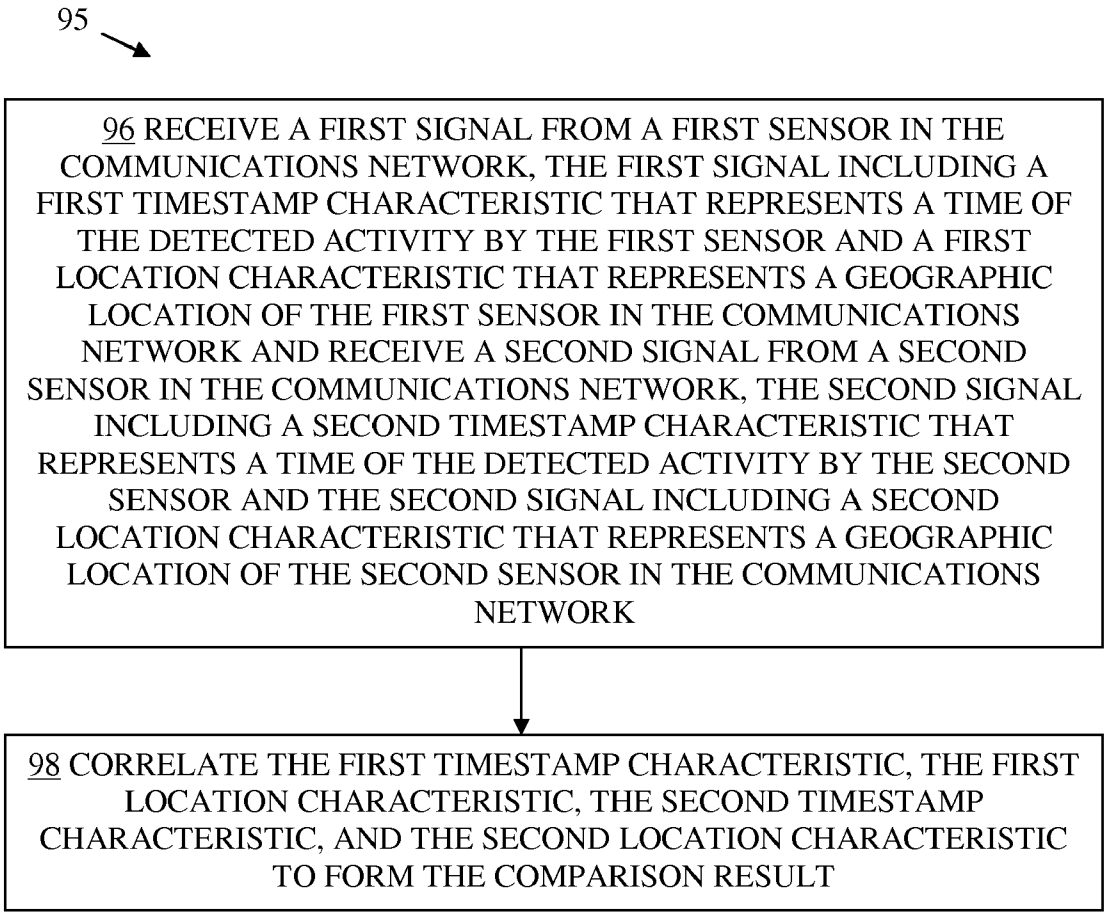
95
96 RECEIVE A FIRST SIGNAL FROM A FIRST SENSOR IN THE COMMUNICATIONS NETWORK, THE FIRST SIGNAL INCLUDING A FIRST TIMESTAMP CHARACTERISTIC THAT REPRESENTS A TIME OF THE DETECTED ACTIVITY BY THE FIRST SENSOR AND A FIRST LOCATION CHARACTERISTIC THAT REPRESENTS A GEOGRAPHIC LOCATION OF THE FIRST SENSOR IN THE COMMUNICATIONS NETWORK AND RECEIVE A SECOND SIGNAL FROM A SECOND SENSOR IN THE COMMUNICATIONS NETWORK, THE SECOND SIGNAL INCLUDING A SECOND TIMESTAMP CHARACTERISTIC THAT REPRESENTS A TIME OF THE DETECTED ACTIVITY BY THE SECOND SENSOR AND THE SECOND SIGNAL INCLUDING A SECOND LOCATION CHARACTERISTIC THAT REPRESENTS A GEOGRAPHIC LOCATION OF THE SECOND SENSOR IN THE COMMUNICATIONS NETWORK
98 CORRELATE THE FIRST TIMESTAMP CHARACTERISTIC, THE FIRST LOCATION CHARACTERISTIC, THE SECOND TIMESTAMP CHARACTERISTIC, AND THE SECOND LOCATION CHARACTERISTIC TO FORM THE COMPARISON RESULT

FIG. 9

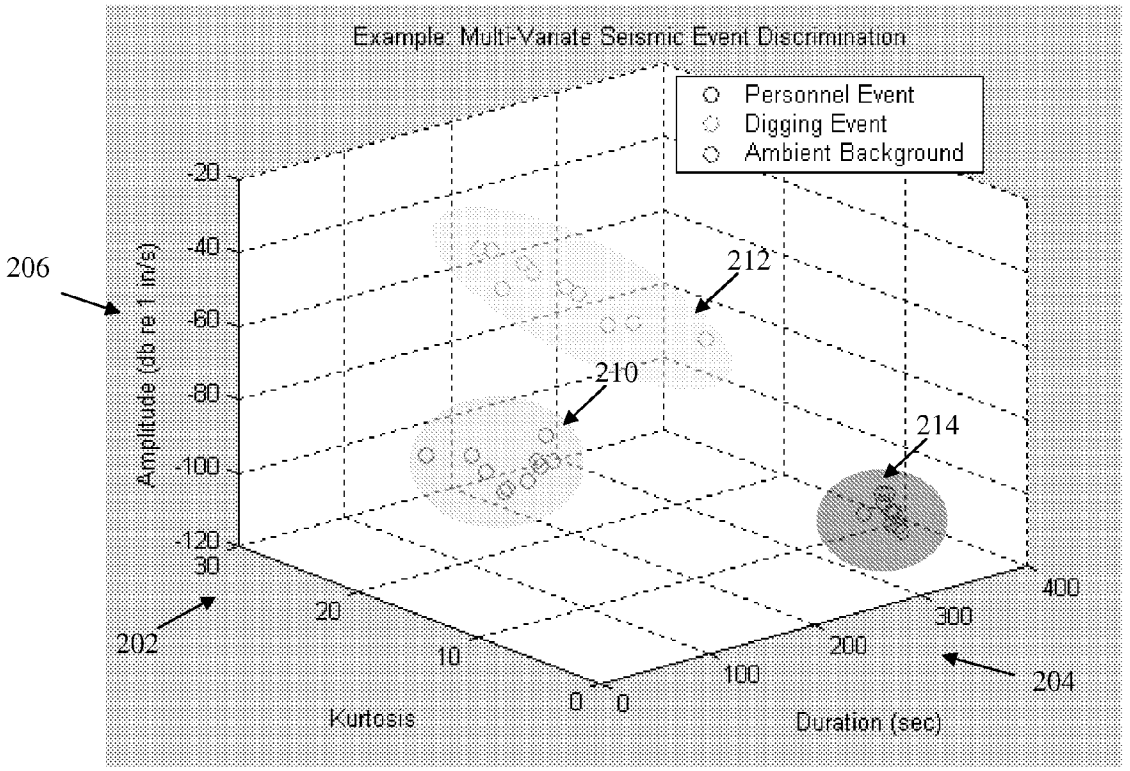
Example: Multi-Variate Seismic Event Discrimination
Personnel Event
Digging Event
Ambient Background
Amplitude (db re 1 in/s)
-20
-40
-60
-80
-100
-120
206
212
210
214
202
204
30
20
10
0
0
100
200
300
400
Kurtosis
Duration (sec)

FIG. 10

BASE STATION AND METHOD FOR DETECTING EMPLACEMENT OF IMPROVISED EXPLOSIVE DEVICES

BACKGROUND

Terrorist-type explosives, such as Improvised Explosive Devices or IEDs, are a source of casualties both in military action and in peacetime. Certain IEDs, such as roadside bombs, are formed of an explosive element, such as one or more 120 mm or 155 mm shells, and a radio controlled detonator. These IEDs are placed along side roadways and typically hidden, buried, or camouflaged. In use, when a triggerman observes a target vehicle traveling toward an emplaced IED, the triggerman remotely detonates the IED using a remote control, thereby causing the IED to explode and cause damage to the target vehicle, injury to the vehicle's personnel, or both.

In order to reduce the risk of an attack by way of the roadside IEDs, military groups typically focus their efforts toward countering the effect of IEDs after emplacement. For example, the military can send personnel and equipment to roadway locations in an attempt to visually detect the presence of IEDs. Once detected, the IEDs can be cleared from the location. The military also utilizes signal jamming techniques to prevent the triggermen from remotely detonating IEDs using the radio controlled detonators. Additionally, the military can increase the amount of armor on military vehicles to limit the potentially destructive effects of the IEDs when detonated in the vehicle's vicinity.

The military also utilizes certain sensor systems to detect movement of personnel and vehicles in a particular area. For example, the Remotely Monitored Battlefield Sensor System (REMBASS) includes remotely monitored sensors placed within a particular geographic location. As personnel enter the area, the sensors detect and locate the personnel within the area and classify the type of personnel, such as wheeled vehicle, tracked vehicle, or pedestrian traffic.

SUMMARY

As described above, the military typically counters IED emplacement efforts after the IEDs have been emplaced within a geographic area using different techniques. However, these techniques suffer from a variety of deficiencies. For example, as described above, the military provides personnel to visually detect the presence of IEDs. However, the enemy can counter this technique by improving the camouflage of the IEDs and increasing the number of IEDs emplaced over a particular geographic area. Also in the case where the military utilizes signal jamming techniques to prevent radio controlled detonators from detonating the IEDs, the enemy can utilize a hard wire remote control or a motion sensor device, such as passive infrared detector, hard wired to the IED. As a vehicle or personnel moves into the detection range of the motion sensor, the motion sensor transmits a signal to the IED, causing it to detonate. Additionally, while the military has added or increased the amount of armor on military vehicles, detonation of larger IEDs, or Explosively Formed Penetrator (EFP) devices, can penetrate the armor plated vehicles and cause damage to the vehicles.

Also as indicated above, the military utilizes sensor systems, such as REMBASS, to detect movement of personnel and vehicles in a particular area. In REMBASS, the sensors typically transmit motion data to a program monitor upon detection of movement within the system. In the case where a REMBASS sensor is located at a relatively large distance away from the program monitor, the sensor requires relatively large amounts of power to successfully transmit the motion data to the monitor, thereby increasing the power requirements of the sensor's power supply and decreasing battery life. Additionally conventional REMBASS program monitors do not discriminate between activities associated with the emplacement of IEDs and "innocent" activities such as the ordinary motion of vehicles or personnel in the vicinity of the sensors. In the case where ordinary pedestrian traffic occurs in proximity to the sensors, in response to the motion data received from the sensors, the program monitor can detect such activity as an IED emplacement activity and generate a false alarm.

In contrast to the conventional IED detection approach, embodiments of the invention are directed to techniques for detecting activity associated with placing an explosive device, such as an IED or landmine, within a particular geographic area. A detection system includes sensors and a base station that detect and report on suspected IED emplacement activity within the area. When disposed within a geographic area, each sensor forms part of a wireless communications network which allows communication among neighboring sensors. As a sensor detects activity in its proximity, such as activity that indicates emplacement of an IED, the sensor transmits a reporting signal through the network to the base station. The base station is operable to detect if the signals received from the sensors are indicative of IED emplacement activity or some other activity (e.g., pedestrian traffic, vehicular traffic) that is not typically associated with IED emplacement activity. Such detection minimizes the generation of improper or false alarm reports for each and every reporting signal that the base station receives from the sensors. In the event that the base station detects activity that is indicative of IED emplacement activity, the base station can direct mobile response units to take immediate responsive action to prevent detonation of the IEDs or apprehend the perpetrators in the act.

In one arrangement, embodiments of the invention relate to a method for detecting placement of an explosive device within a geographic area by a base station. The method includes receiving a signal from at least one sensor in the communications network, the signal including a characteristic that represents a detected activity within a location proximate to the at least one sensor. The method also includes comparing the characteristic of the signal to a baseline characteristic to form a comparison result. Also, the method includes detecting that the characteristic of the signal indicates placement of an explosive device within the geographic area when the comparison result has a first value and that the characteristic of the signal does not indicate placement of an explosive device within the geographic area when the comparison result has a second value. As such, the base station is operable to detect if the signals received from the sensors are indicative of IED emplacement activity or some other activity (e.g., pedestrian traffic, vehicular traffic) that is not typically associated with IED emplacement activity. Such detection minimizes the generation of improper or false alarm reports for each and every reporting signal that the base station receives from the sensors.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following description of particular embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views.

The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. **1** illustrates a schematic representation of a system for detecting placement of an explosive device within a geographic area.

FIG. **2**A illustrates a relative detection range of a sensor for innocent activity versus IED emplacement activity of FIG. **1**.

FIG. **2**B is a graph showing a first type of vibration activity (e.g., innocent person walking) detected by the sensor of FIG. **2**A.

FIG. **2**C is a graph showing a second type of vibration activity detected (IED emplacement) by the sensor of FIG. **2**A.

FIG. **3** illustrates an example of a graphic output produced by the base station after detecting suspected IED emplacement activity.

FIG. **4** illustrates an example of a graphic output produced at a mobile response unit, based upon information received from a base station, to aid in locating suspected IED emplacement activity.

FIG. **5** is a flow chart illustrating a method performed by the system of FIG. **1** for detecting placement of explosives within a geographic area.

FIG. **6** illustrates a schematic representation of the collection, processing, and flow of reporting signals generated within the system of FIG. **1**.

FIG. **7** is a flowchart that illustrates the steps performed by the base station when detecting placement of an explosive device, such as an IED, based upon timestamp information

FIG. **8** is a flowchart that illustrates the steps performed by the base station when detecting emplacement of an IED, based upon location information.

FIG. **9** is a flowchart that illustrates the steps performed by the multi-node feature extraction function when detecting emplacement of an IED, based upon both location and timestamp information.

FIG. **10** is a graph that represents the correlation performed by the base station among three characteristics of multiple input signals received from the network sensors.

DETAILED DESCRIPTION

Embodiments of the invention are directed to techniques for detecting activity associated with placing an explosive device, such as an IED or landmine, within a particular geographic area. A detection system includes sensors and base station that detect and report on suspected IED emplacement activity within the area. When disposed within a geographic area, each sensor forms part of a wireless communications network which allows communication among neighboring sensors. As a sensor detects activity in its proximity, such as activity that indicates emplacement of an IED, the sensor transmits a reporting signal through the network to the base station. The base station is operable to detect if the signals received from the sensors are indicative of IED emplacement activity or some other activity (e.g., pedestrian traffic, vehicular traffic) that is not typically associated with IED emplacement activity. Such detection minimizes the generation of improper or false alarm reports for each and every reporting signal that the base station receives from the sensors. In the event that the base station detects activity that is indicative of IED emplacement activity, the base station can direct mobile response units to take immediate responsive action to prevent detonation of the IEDs or apprehend the perpetrators in the act.

FIG. **1** illustrates one embodiment of a detection system **20** for detecting placement of an explosive device, such as an IED, within a given geographic area. The detection system **20** includes a set of sensors **22**, one or more optional signal repeaters **23**, and a base station **24**. The system **20** provides substantially continuous monitoring of an area for IED emplacement. For example, the sensors **22** and signal repeaters **23** of the system **20** can be installed within a geographic area, such as along a roadside **25**, for surveillance of IED emplacement activity. The base station **24** can be installed within a location remote from the sensors **22** and signal repeaters **23** within the system **20**. The system **20** allows detection and reporting of IED emplacement within the geographic area as it occurs. For example, the sensors **22** transmit, to the base station **24**, reporting signals **36** that can indicate IED placement activity within the area. Based upon an analysis of the signals **36**, the base station **24** or personnel monitoring the base station **24** can direct mobile response units to take responsive action, such as capturing insurgents in the act of emplacement, tracking the insurgents subsequent movements, performing a stake-out at suspected IED sites to apprehend the trigger men, or warning convoys/patrols of suspect locations until the locations are investigated and cleared.

In the system **20**, each sensor **22** is configured to detect activity within a location in proximity to the sensor **22**. In one arrangement, each sensor **22** is configured as a seismic sensor **22** which detects vibrations occurring within a particular distance from the seismic sensor **22**. For example, as shown in FIGS. **2**A-**2**C, for an activity that generates vibrations having relatively small amplitudes, such as caused by pedestrians walking as shown in FIG. **2**B, the seismic sensor **22'** detects such activity within a radius **30** of approximately 25 meters from the seismic sensor **22'** and generates a corresponding reporting signal. However, for activity that produces vibrations having relatively larger amplitudes, such as caused by emplacement of an IED within the ground as shown in FIG. **2**C, the seismic sensor **22'** detects such activity within a radius **32** of considerably greater than 25 meters from the seismic sensor **22'** and generates a corresponding reporting signal.

Returning to FIG. **1**, each sensor **22** is also configured to generate a local reporting signal **36** in response to the input vibration or signal detected by the sensor **22**. In one arrangement, the local reporting signal **36** indicates a characteristic associated with the activity detected in proximity to the sensor **22**. For example, the input vibration includes characteristics, such as a maximum vibration amplitude, a frequency, and a duration of the vibration. The reporting signal **36** generated by the sensor **22**, provides some indication as to these, and other, characteristics associated with the input vibration. For example, the reporting signal provides a peak amplitude of the vibration signal, an average amplitude of the vibration signal, a signal to noise ratio of the vibration signal, a duration of the vibration signal, Kurtosis of the vibration signal, a spectral ratio of the vibration signal, tonality of the vibration signal, and a timestamp characteristic that indicates the time of day at which the sensor **22** detected the vibration signal. Details of these characteristics are provided below. In another arrangement, the sensor **22** is configured to include a geographic identifier or location characteristic with the local reporting signal **36**. For example, the location characteristic provides the base station **24** with an indication as to the geographic origin of the reporting signal.

The sensors **22** form a wireless communications network **34** that allows any single sensor **22** to both send and receive reporting signals **36**, as generated by any of the other sensors **22**, in order to direct the reporting signals **36** toward the base station **24**. For example, each sensor **22** includes a transceiver (not shown) that allows the sensors **22** to transmit and receive

wireless reporting signals **36**. In one embodiment, the transceivers are configured with a communications protocol, such as the IEEE 802.15.4 protocol or the ZigBee protocol that defines a relatively inexpensive ad-hoc, self-forming, self-healing, multi-hop, mesh network. Such a mesh network forms a "daisy chain" from one sensor **22** to another to expand the relatively short transmission range of one sensor **22** over a relatively larger area and to minimize the amount of power required by the sensor **22** to transmit a signal **36**.

With the sensors **22** forming a wireless mesh communications network **34**, each sensor **22** within the communication network **34** acts as a relay point for other neighboring sensors **22** to direct reporting signals **36** toward the base station **24**. As such, each sensor **22** transmits the signals **36** to a limited number of sensors **22** within the communications network **34**. For example, as shown in FIG. **1**, a sensor **22-4** detects activity within its proximity, generates a reporting signal, and transmits the signal **36** to neighboring sensors **22-2**, **22-3**, and **22-5** disposed within its geographic proximity. Each of the neighboring sensors **22-2**, **22-3**, and **22-5** receives the signal **36** and, in turn, transmits the signal **36** to other geographically proximate sensors to direct the signal **36** toward the base station **24**. For example, the sensor **22-5** transmits the reporting signal **36** to neighboring sensors **22-6**, **22-7**, **22-8** to direct the signal to the base station **24**. Sensor **22-3** would not necessarily transmit the reporting signal **36** to sensor **22-1** because the sensor **22-1** is geographically further away from the base station **24** relative to sensor **22-3**. The process of transmission and reception of the reporting signal **36** among neighboring sensors **22** continues until the signal **36** reaches the base station **24**.

While the sensors **22** within the network are configured to transmit reporting signals **36** received from other sensors **22** within the network, such signals being termed remote reporting signals, each sensor **22** can also transmit local reporting signals generated by the sensor **22** itself. As a result, the sensors **22** provide the base station **24** with a substantially comprehensive view of the overall activity within a geographic area. For example, assume sensor **22-6** generates a local reporting signal **36***a* that indicates a locally detected activity. The sensor **22-6** then transmits the local reporting signal **36***a* to neighboring sensors **22-5** and **22-7**. Each sensor **22-5**, **22-7** receives the signal **36***a* as remote reporting signals. In the event that one of the sensors **22-5**, **22-7**, such as sensor **22-7** for example, also detects local activity and generates a local reporting signal **36***b*, the sensor **22-7** then transmits its local reporting signal **36***b* along with the reporting signal **36***a* received from the sensor **22-6** to a neighboring sensor **22-8**. This process repeats until the reporting signals reach the base station **24**.

In the system **20**, the base station **24** is configured to receive reporting signals **36** from the communications network **34**. For example, the base station **24** is configured as a computerized device, such as a personal computer or a laptop computer, and includes a receiving element **38** that receives the reporting signals **36** from the sensors **22** or signal repeaters **23** within the network **34**. While the receiving element **38** can receive the reporting signals **36** in a variety of formats, in one arrangement, the receiving element **38** is configured as a wireless signal receiver that receives the reporting signals **36** wirelessly.

The base station **24** is operable to detect if the signals **36** received from the sensors **22** are indicative of IED emplacement activity or some other activity (e.g., pedestrian traffic, vehicular traffic) that is not typically associated with IED emplacement activity. For example, as will be described in detail below, the base station **24** can compare a characteristic of one or more of the signals **36** received from the network **34** with an associated baseline characteristic, indicative of IED emplacement activity. For example, the base station **24** can include a memory device that stores multiple baseline characteristics indicative of known IED emplacement activity. Based upon the comparison, the base station **24** can detect whether or not the activity reported by the sensors **22** corresponds to probable IED emplacement activity.

In one arrangement, the base station **24** provides a user or base station operator with a notice to indicate that the activity detected by one or more sensors **22** potentially relates to IED emplacement activity. For example, the base station **24** can display one or more characteristics of the received signal **36** and can indicate to the user that, based upon the analysis of the characteristics, the signal **36** is indicative of IED emplacement activity. At this stage, the user can further assess the signal **36** or characteristics associated with the signal **36** and can make a determination as to the "correctness" of the base station's analysis. For example, based upon the user's analysis of the characteristic, the user can decide that the signal **36** or signal characteristic does correspond to an IED emplacement activity and can allow the base station **24** to proceed and generate a reporting output. Alternately, based upon the user's analysis, the user can decide that the signal **36** or signal characteristic is not indicative of IED emplacement and, as a result, can cause the base station **24** to take no further action. In this arrangement, the base station **24** allows the operator to be involved in the detection of IED emplacement activity detection and the generation of false alarms, thereby minimizing the generation of improper or false alarm reports for each and every reporting signal received from the network **34**.

In the case where the base station **24** or its operator detects the reported activity as being indicative of IED emplacement activity, the base station **24** can generate a reporting output to provide an indication regarding suspected IED placement activity within the network **34**. In one arrangement, the base station **24** provides the reporting output as a graphical output. For example, as shown in FIG. **3**, the base station **24** provides a graphical display **40** that indicates the location of the probable IED emplacement activity. As illustrated, the graphical display **40** shows a topologic representation **42** of a particular geographic area of concern, such as a roadway **42** and the locations of the sensors **22** disposed within the area. Further, the graphical display **40** provides the user with an indication **44**, such as by an arrow or other indication, of a particular sensor **22** that has transmitted a reporting signal having characteristic that indicate possible IED placement activity. While the base station **24** can have a variety of configurations to provide reporting output as a graphical display **40**, in one arrangement, the base station **24** is configured as a Geographic Information System (GSI) workstation utilizing Commercial Joint Mapping Toolkit (C/JMTK) software to display a geographical representation of an area in which the sensors **22** are disposed and an overlay representing the relative locations of the sensors **22** within the area.

Based upon the graphical output **40**, the base station operator can operate the base station **24** to transmit alert information to appropriate response channels for investigation of the detected IED emplacement activity. For example, the base station **24** communicates with a reporting network **46**, such as the Force XXI Battle Command, Brigade-and-Below (FBCB2) network, to transmit the alert information to mobile response units **50** for intervention at the activity site. In one arrangement, the base station **24** forms an integrated part of the FBCB2 network **46**, as opposed to operating as a separate, stand-alone unit.

While the alert information can have a variety of configurations, FIG. **4** illustrates an example of alert information **52** provided to the mobile response units **50**. As illustrated, the alert information **52** provides the response units **50** with information related to the identity of the originating sensor **54**, the date and time of the suspected IED placement activity **56**, and the location coordinates of the sensor **58**. Based on the alert information **52**, the response units can take responsive action in a relatively short timeframe, relative to the detection of the suspected IED placement activity.

FIG. **5** is a flowchart **70** that illustrates the steps performed by the base station **24** when detecting placement of an explosive device, such as an IED, within a geographic area.

In step **72**, the base station **24** receives a signal **36** from at least one sensor **22** in the communications network **24**, the signal **36** including a characteristic that represents a detected activity within a location proximate to the sensor **22**. For example, the base station **24** can receive either local or remote reporting signals **36***a*, **36***b* from the sensors **22** within the communications network **34**. The signals **36***a*, **36***b*, as generated by the sensors **22**, include characteristics that are associated with the activity by the sensors **22**. For example, the characteristic can indicate a peak amplitude of the vibration signal, an average amplitude of the vibration signal, a signal to noise ratio of the vibration signal, a duration of the vibration signal, Kurtosis of the vibration signal, a spectral ratio of the vibration signal, tonality of the vibration signal, and a timestamp characteristic that indicates the time of day at which the sensor **22** detected the vibration signal.

In step **74**, the base station **24** compares the characteristic of the signal **36** to a baseline characteristic to form a comparison result. In one arrangement, the base station **24** stores, as a baseline frequency characteristic within a database, a series of frequency spectrum characteristics that correspond to known frequency spectra as measured during actual IED emplacement. When the base station **24** receives a signal **36** having a vibration frequency characteristic that indicates the frequency of the vibration detected at the sensor **22**, the base station **24** compares the vibration frequency characteristic of the signal **36** with the corresponding vibration baseline frequency characteristic.

In step **74**, the base station **24** detects that the characteristic of the signal indicates placement of an explosive device within the geographic area when the comparison result has a first value and that the characteristic of the signal does not indicate placement of an explosive device within the geographic area when the comparison result has a second value. For example, assume the case where the base station **24** compares the vibration frequency characteristic of a signal **36** with the corresponding vibration baseline frequency characteristic. In the case where the base station **34** detects that the vibration frequency characteristic of a signal **36** and the vibration baseline frequency characteristic do not substantially match, the base station **24** can detect that the reporting signal **36** from the sensor **22** is not indicative of IED emplacement activity. However, assume the case where the base station **34** detects that vibration frequency characteristic of a signal **36** and the vibration baseline frequency characteristic do substantially match. In such a case, the base station can detect that the reporting signal **36** is indicative of the presence of possible IED emplacement activity in proximity to the sensor **22**. As a result of detecting the IED emplacement activity, the base station **24** can then generate a reporting output to provide an alert regarding the suspected IED placement activity within the network **34**.

As indicated above, the sensors **22** form part of a communications network **34** and are configured to generate reporting signals **36** that indicate characteristics associated with activity performed in relative proximity to the sensor **22**. Also as indicated, the base station **24** is operable to detect the probability of IED emplacement activity based upon a comparison of the characteristic of the signal and a baseline characteristic. FIG. **6** illustrates a schematic representation of the overall generating, collection, processing, and use of the reporting signals, and their associated characteristics, within the system **20**, according to one embodiment.

As illustrated, in each sensor **22**, a detector or transducer **100** receives an input **102**, such as a locally detected activity, from a location in proximity to the sensor **22**. For example, in the case where the sensor is configured as a seismic sensor, the transducer receives a vibration from an external source. Based upon the input, the detector **100** generates a signal **104** and transmits the signal **104** to a signal conditioning apparatus **106** which can amplify or perform other signal processing on the signal **104**. Next, the signal conditioning apparatus **106** transmits the signal **104** to an analog-to-digital (A/D) converter **108**. A sampling apparatus **110** acquires digital signal samples from the A/D converter and transmits the signal to a noise estimation **114** and CFAR (Constant False Alarm Rate) detector **116** to minimize false and nuisance alarms, needless processing and radio transmissions, and wasted power.

The CFAR detector **116** transmits the resulting signal **118** to a feature extraction function **120** where the signal undergoes a detection process. The feature extraction function **120** processes the signal **118** over both the time and frequency domains to generate a reporting signal that indicates a characteristic of the input **102** received by the sensor **22**. For example, the characteristics included within the reporting signal includes a time tag associated with the date and time sensor **22** received the input **102**, a peak and average amplitude of the signal **118**, signal to noise ratio information related to the signal, statistical information, including Kurtosis information related to the signal (e.g., Kurtosis being a statistical measure of the impulsivity of a signal, such as a heavy object being placed on the ground or shovel being driven into the ground), auto correlation information (e.g., auto-correlation being a measure of the periodicity of a signal, such as walking at a steady pace or machinery in operation), signal duration information, spectral ratio information (e.g., spectral ratio being the ratio the signal strength in one frequency band versus another, such as the signal strength in a high frequency band divided by the signal strength in a low frequency band), and tonality information (e.g., tonality being a measure of the sine wave signal strength with or without harmonics that may be observed as peaks in the frequency domain via a Fourier Transform). The sensor **22** then transmits the resulting reporting signal to the network **34** via transmitter **122**.

As a result of the processing, the controller **224** generates a reporting signal **36** that indicates a characteristic, such a seismic characteristic associated with the input (e.g., input signal) received by the sensor **22**. For example, the reporting signal **36** can include a peak amplitude of a sensor input vibration or signal, an average amplitude of a sensor input signal, a signal to noise ratio of a sensor input signal, a duration of a sensor input signal, kurtosis of a sensor input signal, a spectral ratio of a sensor input signal, tonality of a sensor input signal, and a time of day at which the sensor **22** generated the signal.

When the base station **24** receives the reporting signal **36**, prior to generating or transmitting an alert message indicating suspected IED emplacement activity within a particular geographic area, the base station **24** performs an analysis of the reporting signal **36** which takes into account various factors associated with the signal **36**. In one arrangement, the base

station **24** receives signals **36** from multiple sensors **24** within the network **34** and correlates like characteristics of each of the signals **36** in order to detect the probability that the signals **36** indicate IED emplacement. For example, after the base station **24** receives reporting signals **36** from multiple sensors **22** with the network **34**, a multi-node association function **124** correlates certain signal characteristics, such as time or location information associated with the signals, to detect probable IED emplacement activity. Description of the operation of embodiments of the multi-node association function **124** is provided below.

In one arrangement, the multi-node association function **124** correlates timestamp information among sensors **22** in the network **34** to detect probable IED emplacement activity within the network **34**. In one arrangement timestamp information relates to the time of day at which a sensor **22** generates a reporting signal. FIG. **7** is a flowchart **80** that illustrates the steps performed by the base station **24** when detecting placement of an explosive device, such as an IED, based upon timestamp information.

In step **82**, the base station **24** receives a first signal from a first sensor in the communications network **34** and receives a second signal from a second sensor in the communications network **34** where the first signal includes a first timestamp characteristic that represents a time of the detected activity by the first sensor and the second signal includes a second timestamp characteristic that represents a time of the detected activity by the second sensor. For example, with reference to FIG. **1**, the base station **24** is configured to receive reporting signals **36** from multiple sensors **22-1** through **22-8** in the communications network **34** where each of the signals includes a timestamp that indicates to the time that each sensor **22** generated the signal **36**.

Returning to FIG. **7**, in step **84**, the multi-node association function **124** of the base station **24** compares the first timestamp characteristic of the first signal to second timestamp characteristic of the second signal to form the comparison result. The base station **24** or operator can then detect whether the signals **36** generated by the sensors **22** indicate probable IED emplacement activity based upon the comparison result.

For example, with reference to FIG. **1**, assume the base station **24** receives a signal from sensor **22-1** having a timestamp T, a signal from sensor **22-2** having a timestamp T+1, and a signal from sensor **22-3** having a timestamp T+2. By comparing the timestamp characteristics of each signal from each sensor, **22-1**, **22-2**, **22-3**, the multi-node association function **124** can detect that the sensors **22** generated signals **36** in a particular sequence and at different times. Because the sensors **22-1**, **22-2**, **22-3** transmitted reporting signals to the base station **24** in a particular sequence and at sequentially increasing times, the base station **24** can detect motion of an object, such as personnel or a truck, relative to the sensors **22-1**, **22-2**, **22-3** in the network **34** that is not indicative of IED emplacement. By contrast, assume the base station **24** receives a signal from sensor **22-1** having a timestamp T, a first signal from sensor **22-2** having a timestamp T+1, and a second signal from sensor **22-2** having a timestamp T+2. By comparing the timestamp characteristics of each signal from each sensor, **22-1**, **22-2**, the multi-node association function **124** can detect the motion of some object from a location proximate to the sensors **22-1** to a location proximate to the second sensor **22-2**. Further, the base station **24** can detect that with subsequent activity occurring in proximity to the second sensor **22-2** at a later time, the activity is indicative of IED emplacement.

As indicated above, the multi-node association function **124** can also correlate location information among sensors **22** in the network **34** to detect probable IED emplacement activity within the network **34**. For example, the location information relates to the relative geographic location of the sensor **22** within the network **34**. FIG. **8** is a flowchart **90** that illustrates the steps performed by the base station **24** when detecting emplacement of an IED, based upon location information.

In step **92**, the base station **24** receives a first signal from a first sensor in the communications network **34** and receives a second signal from a second sensor in the communications network where the first signal includes a first location characteristic that represents a geographic location of the first sensor in the communications network **34** and the second signal includes a second location characteristic that represents a geographic location of the second sensor in the communications network **34**. For example, with reference to FIG. **1**, the base station **24** is configured to receive reporting signals **36** from multiple sensors **22-1** through **22-8** in the communications network **34** where each signal **36** includes information that identifies the relative location or coordinates of the sensors **22-1** through **22-8** within the network **34**.

Returning to FIG. **8**, in step **94**, the multi-node association function **124** of the base station **24** compares the first location characteristic of the first sensor to second location characteristic of the second sensor to form a comparison result. Based upon the comparison result, the base station **24** or operator can then detect whether the signals indicate probable IED emplacement activity.

For example, with reference to FIG. **1**, assume the base station **24** first receives a signal from sensor **22-1** having a first location characteristic that indicates positioning of the sensor **22-1** at a perimeter of the communications network **34**. Further assume that the base station **24** next receives a signal from sensor **22-2** having a second location characteristic that indicates a position of the sensor **22-2** at location within the communications network **34** that is geographically closer to the base station **24** relative to the first sensor **22-1**. By comparing the first and second location characteristics of the signals from each of the sensors **22-1**, **22-2**, the multi-node association function **124** can detect movement of an object relative to the sensors **22-1**, **22-2**. With such movement of the object in the network **34**, the base station **24** can detect such activity as not being indicative of IED emplacement but rather as indicative, for example, of general pedestrian traffic within the network. By contrast, assume the base station **24** first receives a signal from the sensor **22-1** having a first location characteristic that indicates the positioning of the sensor **22-1** at the periphery of the communications network **34**. Further assume that the base station **24** then receives an additional signal from the sensor **22-1** having the first location characteristic. By comparing the location characteristics of each signal from the same sensor **22-1**, the base station **24** can detect that there is little to no motion of an object in proximity to the sensor **22-1**. Because the detected activity is localized relative to a single sensor **22-1**, the base station **24** can detect that the activity is indicative of IED emplacement.

The base station **24** also includes additional elements used to detect the possibility that a signal **36** received from the network **34** is indicative of IED emplacement. For example, the base station **24** includes a multi-node feature extraction function **126** which analyzes a combination of the timestamp information and the location information associated with the signals received from the network **34** to detect additional characteristics associated with the signals **36** that can be indicative of IED emplacement activity.

In one arrangement, the multi-node feature extraction function **126** is configured to correlate location information and timestamp information associated with the signals **36** in

order to detect the velocity of an object traveling within the network **34**. Based upon the velocity, the multi-node association function **124** can detect whether or not the signals **36** received from the network **34** correspond to probable IED emplacement activity. FIG. **9** is a flowchart **95** that illustrates the steps performed by the multi-node feature extraction function **126** when detecting emplacement of an IED, based upon both location and timestamp information.

In step **96**, the bases station **24** receives a first signal from a first sensor in the communications network **34** where the first signal includes a first timestamp characteristic that represents a time of the detected activity by the first sensor and a first location characteristic that represents a geographic location of the first sensor in the communications network **34**. The base station **24** also receives a second signal from a second sensor in the communications network **34**, the second signal including a second timestamp characteristic that represents a time of the detected activity by the second sensor and the second signal including a second location characteristic that represents a geographic location of the second sensor in the communications network **34**. For example, with reference to FIG. **1**, the base station **24** can receive reporting signals **36** from multiple sensors **22-1** through **22-8** in the communications network **34** where each signal **36** includes information indicating the relative location of the sensors **22-1** through **22-8** within the network **34** (e.g., relative to the base station **24**) and where each signal **36** includes information indicating the time at which a respective sensor **22** generated the signal.

Returning to FIG. **9**, in step **98** the multi-node feature extraction function **126** correlates the first timestamp characteristic, the first location characteristic, the second timestamp characteristic, and the second location characteristic to form a comparison result. In one arrangement, as indicated above, correlation of these characteristic indicates, as the comparison result, the velocity of an object traveling through the communications network **34**. For example based on the first and second location characteristics, the multi-node feature extraction function **126** can calculate the distance between two sensors that produce the corresponding first and second signals. Also, based upon the first and second timestamp characteristics, the multi-node feature extraction function **126** can calculate a difference in the times at which the two sensors generated the corresponding first and second signals. The ratio of the difference in distance and the difference in times relates to the velocity of the object.

Based upon the resultant velocity (e.g., the comparison result), the multi-node feature extraction function **126** can detect the probability of IED emplacement activity within the network based upon a comparison of the resultant velocity with some relative velocity measurement. For example, when the comparison result has a relatively small velocity value (e.g., 0.1 mph), the base station **24** can detect that an object has slowed or stopped within the network **34** thereby indicating the possibility of IED emplacement activity. By contrast, when the comparison characteristic has a relatively large velocity value (e.g., 30 mph), the base station **24** can detect that the object has not stopped in the network **34** thereby indicating that no IED emplacement activity has occurred.

As described above, the multi-node feature extraction function **126** analyzes both the timestamp information and the location information associated with the signals received from the network **34** to detect a velocity of an object within the network **34** as an indication of possible IED emplacement activity. In one arrangement, the multi-node feature extraction function **126** can analyze either the timestamp information or the location information to detect additional characteristics associated with the signals **36** that can be indicative of IED emplacement activity.

Returning to FIG. **6**, in one arrangement, the multi-node feature extraction function **126** is configured to analyze the time of day at which the sensor **22** generated the reporting signal **36**, based upon the timestamp characteristic, to detect the probability that the reporting signal **36** indicates IED emplacement activity. Typically, IED emplacement activity occurs at nighttime when the IED emplacement personnel are less likely to be visually detected. Therefore, in the case where the multi-node feature extraction function **126** analyzes a signal's timestamp characteristic that indicates a sensor **22** transmitted the signal during the daytime (e.g., during daylight hours), the function **126** can detect the signal **36** as having a low probability of indicating IED emplacement activity. In the case where the multi-node feature extraction function **126** analyzes a signal's timestamp characteristic of that indicates a sensor **22** transmitted the signal during the nighttime, the function **126** can detect the signal **36** as having a high probability of indicating IED emplacement activity.

In one arrangement, the multi-node feature extraction function **126** is also configured to detect possible IED emplacement activity by analyzing the differences between the times that a particular sensor **22** (e.g., from a particular geographic location) generates multiple signals **36**. For example, IED emplacement typically occurs in proximity to one sensor **22** or a small subset of sensors **22** within the network **34**. In the case where the multi-node feature extraction function **126** detects that sequential reporting signals **36** from a particular sensor **22** were generated over a small timeframe (e.g., a few seconds or a few minutes), the function **126** can detect the signal **22** as being indicative of IED emplacement activity. However, in the case where the multi-node feature extraction function **126** detects that sequential reporting signals **36** from a particular sensor **22** were generated over a relatively large window of time (e.g., a several minutes to a few hours), the function **126** can detect the signal **22** as not being indicative of IED emplacement activity but instead being indicative of other activity (e.g., pedestrian traffic) in proximity to the sensor **22**.

In another arrangement, the multi-node feature extraction function **126** is configured to analyze the location of the sensor **22** generating the signal **36**, relative to its geographic location within the communications network **34**, to detect the probability that the reporting signal **36** indicates IED emplacement activity. Typically, IED emplacement activity occurs in relatively close proximity to a roadside **25**. Therefore, with reference to FIG. **1**, assume the case where a sensor **22-7** that is disposed at a relatively large distance from the roadside **25** generates a signal **36** and transits the signal to the base station **24**. When the multi-node feature extraction function **126** analyzes the signal's location characteristic, the function **126** can detect, based upon the location of the sensor **22-7** within the network **34**, that the sensor **22-7** is located at a distance from the roadside **25**. As such, the function **126** can detect the signal **36** as having a low probability of indicating IED emplacement activity. By contrast and with reference to FIG. **1**, assume the case where a sensor **22-5** that is disposed in relatively close proximity to the roadside **25** generates a signal **36** and transits the signal to the base station **24**. When the multi-node feature extraction function **126** analyzes the signal's location characteristic, the function **126** can detect, based upon the location of the sensor **22-5** within the network **34**, that the sensor **22-5** is located relatively close to the

roadside. As such, the function **126** can detect the signal **36** as having a high probability of indicating IED emplacement activity.

In another arrangement, the multi-node feature extraction function **126** is configured to analyze location information from signals **36** received by the base station **24** to detect if the signals **36** were sequentially transmitted from a single sensor **22** or from multiple sensors **22** in the network **34**. For example, IED emplacement typically occurs in a single location for a given duration of time. As a result, the IED emplacement can cause a sensor **22** to generate multiple reporting signals **36**. Therefore, assume the case where the base station **24** receives multiple, sequential reporting signals **36** from a single sensor **22** and the function **126** detects that the signals **36** originate from a single sensor **22**. Based upon such detection, the multi-node feature extraction function **126** can detect the signals **36** as having a high probability of indicating IED emplacement activity.

Returning to FIG. **6**, the base station **24** also includes additional elements used to analyze the reporting signals **36** prior to generating or transmitting an alert message. For example, the base station **24** includes a feature set data base **128**, a feature vector learning function **130**, an activity classifier function, such as a maximum likelihood classifier function **132**, and a man-machine interface **134**.

The feature set database **128**, in one arrangement, stores baseline characteristics for certain known characteristics associated with IED emplacement activity. For example, the feature set database **128** stores baseline characteristics related to a peak amplitude of a vibration signal, an average amplitude of the vibration signal, a signal to noise ratio of the vibration signal, a duration of the vibration signal, Kurtosis of the vibration signal, a spectral ratio of the vibration signal, and a tonality of the vibration signal where the vibration signal is caused by actual IED emplacement activity (e.g., hole digging, dropping of an IED into the hole).

The maximum likelihood classifier function **132** is configured to compare characteristics of the reporting signals **36** with the baseline characteristics stored in the feature set data base **128** to detect probable IED emplacement activity. For example, when the base station **24** receives a signal **36** from the network **34**, as indicated above, the signal **36** includes several characteristics of an input or vibration signal. When base station **24** receives the signal **36**, the maximum likelihood classifier **132** retrieves one or more baseline characteristics, such as the peak amplitude baseline characteristic, from the feature set database **128** and compares the baseline characteristic to a corresponding, selected characteristic of the signal **36** to form a comparison result. For example, in the case where the base station **24** is reviewing a peak amplitude characteristic of a signal **36**, the maximum likelihood classifier function **132** retrieves the corresponding peak amplitude characteristic from the database **12** and compares the characteristics to each other to form a comparison result. In the case where the comparison result indicates a substantial match or correspondence between the baseline characteristic and the selected characteristic of the signal **36**, the maximum likelihood classifier function **132** can detect that the signal **22** indicates probable IED emplacement activity within the network **34**. In the case where the comparison result indicates a substantial mismatch or substantially no correspondence between the baseline characteristic and the selected characteristic of the signal **36**, the maximum likelihood classifier function **132** can detect that the signal **22** is not indicative of IED emplacement activity within the network **34**.

While the activity classifier function **132** can be configured to compare selected characteristics of a signal **36** with a baseline characteristic to detect if the signal **36** indicates probable IED emplacement activity, the activity classifier function can also be configured to perform a statistical analysis of the characteristics of signals received from the sensors **22** in the network to detect probable IED emplacement activity. In one arrangement, the activity classifier function is configured to analyze histograms, first and second order statistics, and mean and covariance values of like characteristics for signals **36** received by the base station **24** to detect whether or not the signals **36** are indicative of IED emplacement activity. For example, high amplitude aperiodic impulsive signals persistent over a certain interval and within a confined area may indicate a high probability of IED emplacement activity independent of a direct comparison to a baseline characteristic.

In another arrangement, the activity classifier function **132** is configured to correlate at least two selected characteristics of the signal **36** to form a comparison result that is indicative of IED emplacement activity within the network **34**. In one arrangement, for multiple signals received, the activity classifier function **132** correlates selected signal characteristics with each other to detect the probability that the signal relates to IED emplacement activity. Based upon the correlation of the signal characteristics, the activity classifier function **132** can detect if the signals **36** are indicative of IED emplacement activity.

For example, FIG. **10** is a graph **200** that represents the correlation performed by the activity classifier function **132** among three characteristics of multiple input signals received from the network sensors **22**. For example, as shown, the activity classifier function **132** correlates the Kurtosis characteristic of an input signal **202**, the duration characteristic of the input signal **204**, and the amplitude of the input signal **206** for multiple input signals received by the base station **24**. Based upon the correlation among the three characteristics, the correlated characteristics fall into particular decision boundaries or zones. The activity classifier function **132** detects whether a group of signals received from the network **34** are indicative of IED emplacement activity based upon the zone or decision boundary into which the correlated characteristics fall. For example, as illustrated, the graph **200** includes three zones: a personnel event zone **210** indicative of personnel movement within the network, a digging event zone **212** indicative of digging such as for IED emplacement, and an ambient background zone **214** indicative of background noise within the network. In the case where the base station **24** receives signals **36** from one or more sensors in the network **34**, the activity classifier function **132** correlates the Kurtosis characteristic **202**, the duration characteristic **204**, and the amplitude **206** of the input signals. When the correlated characteristics fall within the personnel event zone **210**, the activity classifier function **132** can detect the signals as being indicative of personnel movement within the network not indicative of IED emplacement activity. When the correlated characteristics fall within the digging event zone **212**, the activity classifier function **132** can detect the signals as being indicative of IED emplacement activity. When the correlated characteristics fall within the ambient background zone **214**, the activity classifier function **132** can detect the signals as being indicative of background noise not indicative of IED emplacement activity.

As indicated above, the multi-node association function **124**, the multi-node feature extraction function **126**, and the activity classifier function **132** are operable to detect the probability of IED emplacement activity within the geographic area covered by the network **34**. In one arrangement, these functions **124**, **126**, **132** provide an output **133** to the

man-machine interface **134**, such as a computer terminal or display, to allow a base station operator to review the output **133** prior to the base station **24** issuing a reporting output to the reporting network **46**. For example, the base station **24** can display one or more characteristics of the received signal **36** and can indicate to the user that, based upon the analysis of the signal **36**, the characteristic is indicative of IED emplacement activity. At this stage, the user can further assess the characteristic and can make a determination as to the "correctness" of the base station's analysis. Based upon the user's analysis of the output **133**, the user can decide that the output **133** does correspond to an IED emplacement activity and can allow the base station **24** to proceed and generate a reporting output or alarm. Alternately, based upon the user's analysis, the user can decide that the output **133** is not indicative of IED emplacement and, as a result, can cause the base station **24** to take no further action. In this arrangement, the base station **24** allows the operator to be involved in the detection of IED emplacement activity detection, thereby minimizing the generation of false alarms, thereby minimizing the generation of improper or false alarm reports for each and every reporting signal received from the network **34**.

Additionally, the feature learning vector function **130** is used to improve the performance of the system **20**. For example, when an observed feature vector, such as a selected characteristic associated with a signal **36**, is confirmed by the base station operator as being either IED emplacement activity or some other activity, then the selected feature associated with the true classification (e.g., the IED emplacement activity) is stored in the feature set database. The activity classifier function **132** can then utilize the updated information in the feature learning vector function **130**, thereby improving future performance based on past data.

As indicated above, the sensors **22** are configured to communicate with the base station **24** via the wireless network **34**. In one arrangement, the base station **24** is configured to communicate with the sensors **22** via the network **34** and can transmit programming information to each of the sensors **22** to adjust operation parameters of the sensors **22**. As illustrated in FIG. **6**, the base station **24** includes a threshold adjustment mechanism **136** configured to transmit a signal **138** to one or more sensors **22** to adjust a detection threshold of the sensors **22**. For example, assume the detection threshold of a sensor **22** was set such that any activity in proximity to the sensor **22** (e.g., pedestrian foot traffic, vehicular traffic) would cause the sensors **22** to transmit a reporting signal that included characteristics indicating possible IED placement activity. In such a case, the base station **24** can remotely reconfigure the detection threshold sensors **22** via the signal **138** to decrease the detection sensitivity of the sensor **22**. In another example, the base station **24** can adjust the detection threshold of the sensors **22** during expected high activity periods such as during relatively quiet times (e.g. late night).

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

For example, as illustrated in FIG. **1**, the communications network **34** includes eight sensors **221** through **22-8** that provide IED or explosive device emplacement detection within a geographic area. Such illustration is by way of example only. In one arrangement, the communications network **34** can include any number of sensors to provide emplacement detection over a relatively large geographic area. For example, in the case where the sensors **22** form a mesh network, up to 64,000 sensors can be disposed within a geographic area for IED emplacement detection.

For example, as described above, in one embodiment, the sensors **22** in the system **20** are configured as seismic sensors. Such description is by way of example only. In one arrangement, the sensors **22** can be configured as other types of activity detectors as well. For example, the sensors can be configured as visual or thermal video sensors, infrared thermal sensors, acoustic sensors, radar devices, magnetic sensors, pressure sensors, radio frequency sensors, metal detectors, chemical trace sensors, or MEMS accelerometers.

As indicated above, the base station **24** provides feedback to the sensors **22** in the network to adjust the sensor's sensitivity. However, the base station **24** can also provide other types of feedback to control different parameters and operating characteristics of the sensors **22**.

In one arrangement, the base station **24** is also configured to control the amount of power consumed by the sensors **22** based upon environmental and geographic conditions. For example, as indicated above, typical IED emplacement activity may occur primarily at nighttime. To conserve power when the sensors **22** are least likely to sense an IED emplacement activity, the base station **24** can be configured to send a "power off" command to the sensors **24** in the network **34** to turn off one or more of the sensors **22** during the daylight hours and to send a "power on" command to the sensors **22** to cause the sensors **22** to resume detection activity during nighttime hours. In another example, IED emplacement activity typically occurs along a roadside. However, sensors **22** of the communications network **34** can be distributed within a relatively large geographic area such that certain sensors **22** are disposed within relatively close proximity (e.g. 25 meters) to a roadside while other sensors **22** are disposed at locations that are at a relatively large distance (e.g., greater than 25 meters) from the roadside. To conserve power among a subset of the sensors **22** in the network **34**, the base station **24** can transmit a "power off" command to the sensors **22** that are not near the roadside while maintaining the sensors **22** located in proximity to the roadside in an "on" mode of operation.

In another arrangement, and with reference to FIG. **6**, the base station **24** can also transmit commands to the sensor nodes **22** to cause the sensors **34** to consider reports received from nearby peer sensors prior to transmitting the reports within the network. For example, each sensor can include a peer correlation function (not shown) configured to detect redundancy of a report in the network **34**, relative to other reports generated in the network **34**, prior to transmitting the report. As such, by limiting the transmission of redundant reports, the base station **24** limits wasting of power by the sensors **22** sending redundant reports.

As indicated above, after the base station **24** receives reporting signals **36** from multiple sensors **22** with the network **34**, the multi-node association function **124** correlates certain signal characteristics, such as time or location information associated with the signals, to detect probable IED emplacement activity. It should be understood that the multi-node association function can correlate other signal characteristics as well. For example, the multi-node association function **124** can correlate signal characteristic can indicate a peak amplitude of an input vibration signal, an average amplitude of the vibration signal, a signal to noise ratio of the vibration signal, a duration of the vibration signal, Kurtosis of the vibration signal, a spectral ratio of the vibration signal, and a tonality of the vibration signal to detect probable IED emplacement activity.

What is claimed is:

1. In a base station of a communications network, a method for detecting placement of an explosive device within a geographic area, comprising:

receiving, by the base station, a signal from at least one sensor in the communications network, the signal including a characteristic that represents a detected activity within a location proximate to the at least one sensor;

comparing, by the base station, the characteristic of the signal to a baseline characteristic to form a comparison result; and

detecting, by the base station, (i) that the characteristic of the signal indicates placement of an explosive device within the geographic area, prior to detonation of the explosive device, when the comparison result has a first value and (ii) that the characteristic of the signal does not indicate placement of an explosive device within the geographic area when the comparison result has a second value;

receiving comprises (i) receiving, by the base station, a first signal from a first sensor in the communications network, the first signal including a first location characteristic that represents a geographic location of the first sensor in the communications network and (ii) receiving, by the base station, a second signal from a second sensor in the communications network, the second signal including a second location characteristic that represents a geographic location of the second sensor in the communications network;

comparing comprises further comparing, by the base station, the first location characteristic of the first sensor to second location characteristic of the second sensor to form the comparison result;

comparing, by the base station, the first location characteristic of the first sensor to second location characteristic of the second sensor to form the comparison result comprises comparing, by the base station, the first location characteristic of the first sensor to second location characteristic of the second sensor to detect a level of movement of an object relative to the first sensor and the second sensor; and

detecting, by the base station, (i) that the characteristic of the signal indicates placement of an explosive device within the geographic area when the comparison result has a first value and (ii) that the characteristic of the signal does not indicate placement of an explosive device within the geographic area when the comparison result has a second value comprises detecting, by the base station, (i) that the level of movement of the object relative to the first sensor and the second sensor indicates placement of an explosive device within the geographic area when the level of movement indicates movement in proximity to one of the first sensor and the second sensor and (ii) that the level of movement of the object relative to the first sensor and the second sensor does not indicate placement of an explosive device within the geographic area when the level of movement indicates movement in proximity to both of the first sensor and the second sensor.

2. The method of claim 1, comprising generating, by the base station, a reporting output in response to detecting that the characteristic of the signal indicates placement of the explosive device within the geographic area.

3. The method of claim 2, wherein generating, by the base station, the reporting output comprises generating a graphical output showing a representation of the geographic area and a location of the at least one sensor generating the reporting signal.

4. The method of claim 1, wherein:

receiving comprises (i) receiving, by the base station, a first signal from a first sensor in the communications network, the first signal including a first timestamp characteristic that represents a time of the detected activity by the first sensor and (ii) receiving, by the base station, a second signal from a second sensor in the communications network, the second signal including a second timestamp characteristic that represents a time of the detected activity by the second sensor; and

comparing comprises further comparing, by the base station, the first timestamp characteristic of the first signal to second timestamp characteristic of the second signal to form the comparison result.

5. The method of claim 1, wherein

receiving comprises (i) receiving, by the base station, a first signal from a first sensor in the communications network, the first signal including a first timestamp characteristic that represents a time of the detected activity by the first sensor and a first location characteristic that represents a geographic location of the first sensor in the communications network and (ii) receiving a second signal from a second sensor in the communications network, the second signal including a second timestamp characteristic that represents a time of the detected activity by the second sensor and the second signal including a second location characteristic that represents a geographic location of the second sensor in the communications network; and

comparing comprises correlating, by the base station, the first timestamp characteristic, the first location characteristic, the second timestamp characteristic, and the second location characteristic to form the comparison result.

6. The method of claim 5, wherein:

correlating, by the base station, the first timestamp characteristic, the first location characteristic, the second timestamp characteristic, and the second location characteristic to form the comparison result comprises correlating, by the base station, the first timestamp characteristic, the first location characteristic, the second timestamp characteristic, and the second location characteristic to detect a velocity of an object within the communications network; and

detecting, by the base station, (i) that the characteristic of the signal indicates placement of an explosive device within the geographic area when the comparison result has a first value and (ii) that the characteristic of the signal does not indicate placement of an explosive device within the geographic area when the comparison result has a second value comprises detecting, by the base station, (i) that the velocity of the object within the communications network indicates placement of an explosive device within the geographic area when the velocity has a first value and (ii) that the velocity of the object within the communications network does not indicate placement of an explosive device within the geographic area when the velocity has a second value.

7. The method of claim 1, wherein the characteristic of the signal is selected from a group consisting of: a peak amplitude of a sensor input vibration, an average amplitude of a sensor input vibration, a signal to noise ratio of a sensor input vibration, a duration of a sensor input vibration, Kurtosis of a sensor input vibration, a spectral ratio of a sensor input vibra-

tion, tonality of a sensor input vibration, and a time of day at which the sensor generated the signal.

8. The method of claim **7**, wherein comparing comprises correlating, by the base station, at least two selected characteristics of the signal to form the comparison result.

9. The method of claim **1**, wherein comparing comprises:

retrieving, by the base station, the baseline characteristic, corresponding to a selected characteristic of the signal, from a database of baseline characteristics; and

comparing, by the base station, the selected characteristic of the signal to the baseline characteristic for the selected characteristic to form the comparison result.

10. The method of claim **9**, comprising storing, by the base station, the selected characteristic as the corresponding baseline characteristic in the database based upon the comparison result.

11. The method of claim **1**, comprising adjusting, by the base station, a detection threshold associated with the at least one sensor of the communication network to adjust a detection sensitivity of the at least one sensor.

12. The method of claim **1**, wherein receiving, by the base station, the signal from the at least one sensor in the communications network, the signal including the characteristic that represents the detected activity within a location proximate to the at least one sensor comprises receiving, by the base station, the signal from the at least one sensor via wireless communications over the communications network, the at least one sensor being distinct from the base station.

13. A base station of a communications network, the base station operable to detect placement of an explosive device within a geographic area, the base station having a signal analyzer configured to:

receive a signal from at least one sensor in the communications network, the signal including a characteristic that represents a detected activity within a location proximate to the at least one sensor;

compare the characteristic of the signal to a baseline characteristic to form a comparison result; and

detect (i) that the characteristic of the signal indicates placement of an explosive device within the geographic area, prior to detonation of the explosive device, when the comparison result has a first value and (ii) that the characteristic of the signal does not indicate placement of an explosive device within the geographic area when the comparison result has a second value;

when receiving the signal from at least one sensor in the communications network, the signal analyzer is configured to (i) receive a first signal from a first sensor in the communications network, the first signal including a first location characteristic that represents a geographic location of the first sensor in the communications network and (ii) receive a second signal from a second sensor in the communications network, the second signal including a second location characteristic that represents a geographic location of the second sensor in the communications network;

when comparing the characteristic of the signal to the baseline characteristic to form the comparison result, the signal analyzer is configured to further compare the first location characteristic of the first sensor to second location characteristic of the second sensor to detect a level of movement of an object relative to the first sensor and the second sensor; and

detect (i) that the characteristic of the signal indicates placement of an explosive device within the geographic area when the comparison result has a first value and (ii) that the characteristic of the signal does not indicate placement of an explosive device within the geographic area when the comparison result has a second value comprises detecting, by the base station, (i) that the level of movement of the object relative to the first sensor and the second sensor indicates placement of an explosive device within the geographic area when the level of movement indicates movement in proximity to one of the first sensor and the second sensor and (ii) that the level of movement of the object relative to the first sensor and the second sensor does not indicate placement of an explosive device within the geographic area when the level of movement indicates movement in proximity to both of the first sensor and the second sensor.

14. The base station of claim **13**, wherein the base station is configured to generate a reporting output in response to detecting that the characteristic of the signal indicates placement of the explosive device within the geographic area.

15. The base station of claim **14**, wherein, when generating the reporting output, the base station is configured to generate a graphical output showing a representation of the geographic area and a location of the at least one sensor generating the reporting signal.

16. The base station of claim **13**, wherein:

when receiving, the base station is configured to (i) receive a first signal from a first sensor in the communications network, the first signal including a first timestamp characteristic that represents a time of the detected activity by the first sensor and (ii) receive a second signal from a second sensor in the communications network, the second signal including a second timestamp characteristic that represents a time of the detected activity by the second sensor; and

when comparing, the base station is configured to further compare the first timestamp characteristic of the first signal to second timestamp characteristic of the second signal to form the comparison result.

17. The base station of claim **13**, wherein

when receiving, the base station is configured to (i) receive a first signal from a first sensor in the communications network, the first signal including a first timestamp characteristic that represents a time of the detected activity by the first sensor and a first location characteristic that represents a geographic location of the first sensor in the communications network and (ii) receive a second signal from a second sensor in the communications network, the second signal including a second timestamp characteristic that represents a time of the detected activity by the second sensor and the second signal including a second location characteristic that represents a geographic location of the second sensor in the communications network; and

when comparing, the base station is configured to correlate the first timestamp characteristic, the first location characteristic, the second timestamp characteristic, and the second location characteristic to form the comparison result.

18. The base station of claim **13**, wherein the characteristic of the signal is selected from a group consisting of: a peak amplitude of a sensor input vibration, an average amplitude of a sensor input vibration, a signal to noise ratio of a sensor input vibration, a duration of a sensor input vibration, Kurtosis of a sensor input vibration, a spectral ratio of a sensor input vibration, tonality of a sensor input vibration, and a time of day at which the sensor generated the signal.

19. The base station of claim 18, wherein, when comparing, the base station is configured to correlate at least two selected characteristics of the signal to form the comparison result.

20. The base station of claim 13, wherein when comparing, the base station is configured to:

retrieve the baseline characteristic, corresponding to a selected characteristic of the signal, from a database of baseline characteristics; and

compare the selected characteristic of the signal to the baseline characteristic for the selected characteristic to form the comparison result.

21. The base station of claim 20, wherein the base station is configured to store the selected characteristic as the corresponding baseline characteristic in the database based upon the comparison result.

22. The base station of claim 13, wherein the base station is configured to adjust a detection threshold associated with the at least one sensor of the communication network to adjust a detection sensitivity of the at least one sensor.

23. In a base station of a communications network, a method for detecting placement of an explosive device within a geographic area, comprising:

receiving, by the base station, a first signal from a first sensor in the communications network, the first signal including a first location characteristic that represents a geographic location of the first sensor in the communications network;

receiving, by the base station, a second signal from a second sensor in the communications network, the second signal including a second location characteristic that represents a geographic location of the second sensor in the communications network;

comparing, by the base station, a first location characteristic of the first sensor to a second location characteristic of the second sensor to detect a level of movement of an object relative to the first sensor and the second sensor; and

detecting, by the base station, (i) that the level of movement of the object relative to the first sensor and the second sensor indicates placement of an explosive device within the geographic area when the level of movement indicates movement in proximity to one of the first sensor and the second sensor and (ii) that the level of movement of the object relative to the first sensor and the second sensor does not indicate placement of an explosive device within the geographic area when the level of movement indicates movement in proximity to both of the first sensor and the second sensor.

24. In a base station of a communications network, a method for detecting placement of an explosive device within a geographic area, comprising:

receiving, by the base station, a first signal from a first sensor in the communications network, the first signal including a first timestamp characteristic that represents a time of the detected activity by the first sensor and a first location characteristic that represents a geographic location of the first sensor in the communications network;

receiving a second signal from a second sensor in the communications network, the second signal including a second timestamp characteristic that represents a time of the detected activity by the second sensor and the second signal including a second location characteristic that represents a geographic location of the second sensor in the communications network;

correlating, by the base station, the first timestamp characteristic, the first location characteristic, the second timestamp characteristic, and the second location characteristic to detect a velocity of an object within the communications network; and

detecting, by the base station, (i) that the velocity of the object within the communications network indicates placement of an explosive device within the geographic area when the velocity has a first value and (ii) that the velocity of the object within the communications network does not indicate placement of an explosive device within the geographic area when the velocity has a second value.

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